GRAPHICAL AND STATISTICAL ANALYSIS OF LONG-TERM SOIL ACIDITY MONITORING DATA 1981-2003

106-00033/

GRAPHICAL AND STATISTICAL ANALYSIS OF LONG-TERM SOIL ACIDITY MONITORING DATA 1981-2003

Prepared for:

Alberta Environment
10th Floor Oxbridge Place
9820 – 106 Street
Edmonton, AB
T5K 2J6

Prepared by:

Timberline Forest Inventory Consultants
Suite 315 10357 – 109 Street.
Edmonton, AB
T5J 1N3

March 20, 2004

Pub No. T/777

ISBN No. 0-7785-3955-5 (Printed Edition)

ISBN No. 0-7785-3978-4 (On-line Edition)

Web Site: http://www3.gov.ab.ca/env/info/infocentre/publist.cfm

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Environmental Monitoring and Evaluation Branch
Alberta Environment
10th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-6225
Fax: (780) 427-7958

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email:

SUMMARY

In 1981, Alberta Environment developed a long-term monitoring program to assess the impacts of acid deposition on soil quality. A total of 8 sites were situated in selected areas of the province, based upon regional acidic depositions, highly sensitive soils, and areas that would be expected to be undisturbed for the lifespan of the project. A sampling schedule was developed that would carry the program through for a period of 44 years (60 years at the Fort McMurray site). Since 1981, 5 sampling events have occurred at most of the sites, and the data collected to date has been compiled and analyzed in this report. Soil quality as measured by pH, base saturation, calcium:aluminum ratio and base cation:aluminum ratio has been assessed for each of the sites.

The sites in the grasslands area of the province (Twin Butte and Esther) appear to be well buffered, and have not shown significant declines in indicator parameters. The remaining sites (Bruderheim, Devon, Cold Lake, Fort McMurray, High Prairie, Rocky Mountain House) are in the Parkland or Boreal forested zones of Alberta, and declines in pH and base saturation rates have been noted at some, but not all sites. The site at Fort McMurray has shown a slight increase in pH, but has the lowest base saturation rate of all of the sites. Base cation to aluminum ratio and calcium to aluminum ratio showed variations within some sites, but there were no overall trends associated with these parameters over time.

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 GRAPHICAL AND STATISTICAL ANALYSIS 1

2.1 Soil Chemistry Data 1

3.0 SOFTWARE AND PROCEDURES 2

3.1 Data Input and Conditioning 2

4.0 DISCUSSION 4

5.0 RECOMMENDATIONS 5

6.0 REFERENCES 5

7.0 APPENDIX 1. SOIL ACIDITY INDICATORS: TABLES AND GRAPHS 6

8.0 APPENDIX 2. SAS® CODE FOR DATA INPUT, STATISTICAL ANALYSIS, AND OUTPUT TO EXCEL® 22

9.0 APPENDIX 3. INFLUENCE OF OUTLIERS ON STATISTICAL CALCULATIONS 28

TABLE OF TABLES

Table 1	**Summary of site and climatic data for Natural Subregions within which sample sites occur**	3
Table 2	**Soil acidity indicator summary: Bruderheim west block (depths in cm)**	6
Table 3	**Soil acidity indicator summary: Cold Lake east block (depths in cm)**	8
Table 4	**Soil acidity indicator summary: Devon north block (depths in cm)**	10
Table 5	**Soil acidity indicator summary: Esther north block (depths in cm)**	12
Table 6	**Soil acidity indicator summary: Fort McMurray north block (depths in cm)**	14
Table 7	**Soil acidity indicator summary: High Prairie east block (depths in cm)**	16
Table 8	**Soil acidity indicator summary: Rocky Mountain House south block (depths in cm)**	18
Table 9	**Soil acidity indicator summary: Twin Butte west block (depths in cm)**	20

TABLE OF FIGURES

Figure 1 Soil acidity indicator summary: Bruderheim west block 7
Figure 2 Soil acidity indicator summary: Cold Lake east block.....9
Figure 3 Soil acidity indicator summary: Devon north block.....11
Figure 4 Soil acidity indicator summary: Esther north block 13
Figure 5 Soil acidity indicator summary: Fort McMurray north block.....15
Figure 6 Soil acidity indicator summary: High Prairie east block.....17
Figure 7 Soil acidity indicator summary: Rocky Mountain House south block 19
Figure 8 Soil acidity indicator summary: Twin Butte west block 21

1.0 Introduction

In January 2004, Alberta Environment contracted Timberline Forest Inventory Consultants to conduct data analysis and basic data interpretation of a dataset containing soil chemical analysis data. These data have been collected at regular intervals at eight sites (six coniferous forest sites and two grassland sites, mostly on coarse-textured soils) across the province since 1981 in support of the Long Term Soil Acidity Monitoring (LTSAM) program. The LTSAM program was initiated in 1981 to monitor long-term changes in soil acidity. A previous report (Roberts et al. 1989) provides detailed information on the sampling frame, methods for data collection, and soil characteristics, and presents the results of data analyses from 1981 to 1988 following the first two sampling events at each of the eight sites.

Alberta Environment intends to complete a comprehensive report on the first five sampling events (1981-2003). This statistical summary will assist in the preparation of that report by summarizing four soil acidity indicators for each of eight sites over up to five measurement periods. The four soil acidity indicators are pH, base saturation percentage, base cation to aluminum ratio and calcium to aluminum ratio. The changes in these indicators over time are summarized by site and sample depth and the statistics are presented as tables and graphs in Appendix 1.

The main body of this report outlines the steps that were taken with respect to data preparation, software and procedures used, and assumptions made in handling the data. The site information presented in Roberts et al. (1989) is augmented by a tabular presentation of the climatic characteristics for the natural subregions within which each of the eight sample plots occurs. This report also makes comments on possible data limitations and provides some recommendations related to improving ongoing sampling and analysis.

2.0 GRAPHICAL AND STATISTICAL ANALYSIS

2.1 Soil Chemistry Data

A 5,692 record dataset covering five measurement periods, provided by Alberta Environment in Excel® workbook format, formed the basis of this analysis. The dataset included a detailed location of site, block, replicate, depth of sampling, sample year, and different soil chemical indicators. Eight separate data spreadsheets, one for each area sampled, were included in the workbook. Three information sheets describing sample date, detection sensitivity levels and formulae used in converting data were also provided for information purposes. In the data spreadsheets for each site, six of the 28 measurement columns were directly used for this analysis (pH, base saturation percentage, base saturation indicator one, base saturation indicator two[1], base cation to aluminum ratio and calcium to aluminum ratio). The other measurements included with the worksheets provided the data necessary to calculate these six measurements according to the formulae included in the workbook.

According to the original experimental design described in Roberts et al. (1989), two replicate blocks were set up on each sample site to ensure that samples would be available from at least

[1] These are checks on the base saturation data (G. Byrtus, Alberta Environment, pers. comm. February 20 2004)

one block should the site be affected by disturbance[2]; the samples from each block were not all analyzed for a given sampling period because of financial constraints. Therefore, the block that had analysis data for the most sampling periods was selected for analysis and presentation for this report. At two of eight study sites, both blocks at each site had the same number of measurements. In these cases, the block to be presented was randomly selected; the assumption made in the random selection was that either of the blocks would represent the site equally well. Table 1 provides a brief overview of climatic and site information pertaining to natural subregions within which the study sites are located. Detailed soil profile information and more information on geomorphology at each site is provided in Roberts et al. (1989).

3.0 Software and Procedures

3.1 Data Input and Conditioning

Data selection, conditioning and analysis were conducted with SAS® statistical software; graphs were produced through MS Excel® as requested by Alberta Environment. Several procedures and modules in SAS were used. The dynamic data exchange module (DDE) was used to input data from Excel® to SAS® for analysis and to export data from SAS® to Excel® for graphing. The SAS® SQL procedure was used to select eligible data for analysis; the SAS® means procedure was used to produce summary statistics and the tables in Appendix 1. The SAS® syntax for data input, conditioning, and analysis is included with this report as Appendix 2. Other SAS® printing and plotting procedures were used to explore the data and search for relationships among soil acidity indicators (not reported in this document).

Measured values from depths of 2, 5 and 10 cm were analyzed, as these depths had the most complete set of measurements across periods for all sites; sampling below 15 cm was stopped in the 2000 sampling period for budgetary reasons. Water-soluble cation data, including aluminum values, were not obtained for the fourth sampling period for any sample site and cannot be presented in the tables and graphs in Appendix 1. On most sites, pH and base saturation percentage were measured five times; there were only four measurements at the Fort McMurray site. Missing aluminum values for three measurements out of 5692 meant that base cation to aluminum ratio and calcium to aluminum ratio could not be calculated, and those observations were excluded from this analysis.

Appendix 3 provides an illustration of how influential single measurements can be. In the example shown (Twin Butte), the Ca:Al and base cation:Al ratios for replicate A in the west block in 1986 are 621 and 969, respectively – well above ratios for other replicates in the same block. The left-hand charts show the consequences of removing the outliers for base cation:Al (top left-hand chart) and Ca:Al (bottom left-hand chart); the spike in means and the size of the error bar are substantially lower than on the corresponding right-hand charts.

---

[2] In fact, this did happen to three study sites. A gravel pit was developed adjacent to a site at Rocky Island, near Fort McMurray (G. Dinwoodie, Alberta Environment, pers. comm.). Dust or other emissions from activities in the pit could affect soil acidity measurements, so the site was abandoned and is not included in this study. The plot at Bruderheim was disturbed by a fire access line that cut through one block of the pair at the plot. One block at High Prairie was partially destroyed by a cutline. The disturbed area was relocated on the opposite side of the undisturbed portion of the block.

Table 1 Summary of site and climatic data for Natural Subregions within which sample sites occur

Site	Block	Legal description (twp-rge-M)	Vegetation and parent material	Natural Subregion	Climate Data[1]					
					Median annual temp (C)	Median summer temp (C)	Median winter temp (C)	Median annual precipitation (mm)	Moisture deficit	Median Growing degree days (>5C)
Bruderheim	W	56-20-w4	Pine woodland; ridged sandy eolian blanket	Central Parkland	3.3	14.4	-8.7	412	-233	1257
Cold Lake	E	64-2-w4	Pine woodland; sandy glaciofluvial blanket or veneer over loamy moraine	Central Mixedwood	0.8	13.5	-13.20	397	-213	1143
Devon	S	51-26-w4	Pine woodland; sandy ridged eolian blanket	Central Parkland	3.3	14.4	-8.7	412	-233	1257
Esther	N	31-2-w4	Grazed grassland; sandy glaciofluvial blanket	Dry Mixedgrass	5	16.2	-7.2	272	-533	1594
Ft. McMurray	N	93-9-w4	Pine woodland, rapidly drained, sandy glaciofluvial blanket	Central Mixedwood	0.8	13.5	-13.20	397	-213	1143
High Prairie	E	75-17-w5	Pine woodland; sandy eolian veneer over sandy glaciofluvial	Dry Mixedwood	0.8	13.8	-10.5	380	-265	1150
Rocky Mtn. House	S	38-8-w5	Pine woodland; ridged sandy eolian blanket	Lower Foothills	3.0	12.0	-7.8	464	-80	1008
Twin Butte	W	5-29-w4	Grazed grassland; Loamy and clayey morainal materials, well drained	Foothills Fescue	5.1	13.8	-3.9	445	-411	1200

Climate data summary source: Strong, W.L. and K. Leggat. 1992. Ecoregions and ecodistricts of Alberta. Alberta Forestry, Lands and Wildlife unpublished report.

4.0 Discussion

The graphical and tabular statistics presented in Appendix 1 reveal the following general visual trends in the data. Stated inferences regarding the statistical significance of these trends are supported by a Scheffé multiple-range means test done for each of the four indicator variables to compare yearly variations within horizons at each study location. Results of this test were provided to Alberta Environment as a *.pdf file on CD.

- Five of the eight sites (Bruderheim, Devon, Rocky Mountain House, High Prairie, Cold Lake) show a decline in soil pH value in the 2 and 5 cm depth profiles over time indicating that surface soil acidity is increasing. Base saturation rates declined with time at all of these sites. Some differences are statistically significant.
- The graphs and tables for the Fort McMurray site show a slight increase in pH over time; this was not statistically significant. This site had the lowest base saturation rate of any site at the last measurement period.
- The two grassland sites (Esther, Twin Butte) did not display significant trends in pH or in base saturation. At the Twin Butte site, this could be partly due to the inherent buffering capacity of loamy/clayey morainal sediments.
- Base cation to aluminum ratio and calcium to aluminum ratio showed statistically significant variations within some sites over time, but there were no evident overall patterns common to all sites over time. Both grassland sites (Esther, Twin Butte) had much higher ratios for both Ca:Al and base cation:Al parameters than the forest sites.
- Some sites showed a pattern of increasing standard error, indicating a higher degree of variability about the mean, in the latest measurement periods. There are at least three factors other than naturally occurring variability that could singly or in combination have contributed to higher variation:
    - There could have been an actual within-block variation between samples;
    - There could have been differences in soil collection or analysis techniques between samples within blocks; or
    - There could have been data entry errors.

  It is recommended that sampling and analysis procedures for the latest analysis period be compared to those for previous periods to ensure consistency.
- There are some extreme outliers that significantly affect trends in block statistics. The most extreme case was described above under "Data Input and Conditioning" and is illustrated in Appendix 3. Outliers may be a partial consequence of the same factors listed above that contribute to higher standard errors.

5.0 Recommendations

The study as designed appears to be statistically sound, and there are at least six more sampling events planned during the total lifespan of at least 44 years envisioned for this project. The Bruderheim site should be assessed to determine whether sampling and analysis should focus on the other block. Although the sites have not been fenced out so that they are not readily visible to the public, they should be monitored on at least an annual basis to determine whether access by humans or livestock may impact their natural state. Both the grassland sites are grazed and it is possible that soil compaction, cowpats and urine could modify the surface soil chemistry quite substantially in local areas.

Because there is a good possibility that soil analysis techniques will change over the next two decades, those techniques that have been and are currently being used should be thoroughly documented. If changes to analysis techniques are contemplated, an appropriate set of conversion factors might need to be developed to ensure that it is changes to soil at the site and not changes to analysis techniques that have produced the observed trends in soil acidity indicators. Splitting well-mixed double samples and comparing the results of split sample analyses from the same sample pit and horizon is one way to check on within-horizon variability due to analysis procedures.

The influence of outlier data points on statistical trends can be marked, as the discussion under "Data Input and Conditioning" shows. It might be advisable to set reasonable outer limits based on the characteristics of the data; for example, flag and eliminate all observations that are greater than three standard deviations from the mean. Alternatively, define upper and lower limits that are conventionally accepted or that could be reached through a survey of expert opinion for the parameter in question.

Finally, perhaps a more intensive search for the causal factors that might be contributing to soil acidity changes should be initiated. Roberts et al. (1989, p. 5) indicate that the primary reasons for establishing the various sites are to assess long-range transport possibilities for airborne acid deposition. There is no mention of corresponding air quality data collection at or near the sample sites, however. It may be advisable to augment soil acidity measurements with atmospheric measurements at the sites to develop linkages between these parameters that could be applied elsewhere to similar sites in the same subregions. It might also be valuable to know how the blocks are situated on the landforms at each site. For example, some sites are noted as occurring on ridged eolian or glaciofluvial materials, and it might make a difference to acid deposition rates depending on the placement of the block on or between ridges and the orientation of the ridges. Site photographs would be helpful if they do not already exist, and possibly some consideration should also be given to plant vigor observations (e.g., necroses, tree mortality) that can reliably be associated with soil chemical changes and separated from other site influences such as short-term climatic effects, grazing effects, or other mechanical/chemical factors.

6.0 References

Roberts, T.L., Nason, G.E., Regier, H. 1989. Long-term soil acidification monitoring in Alberta from 1981 to 1988 (Draft). Soil Protection Branch, Wastes and Chemicals Division. Alberta Environment. Lethbridge. 175 pp.

7.0 APPENDIX 1. Soil Acidity Indicators: Tables And Graphs

Table 1 Soil acidity indicator summary: Bruderheim west block (depths in cm)

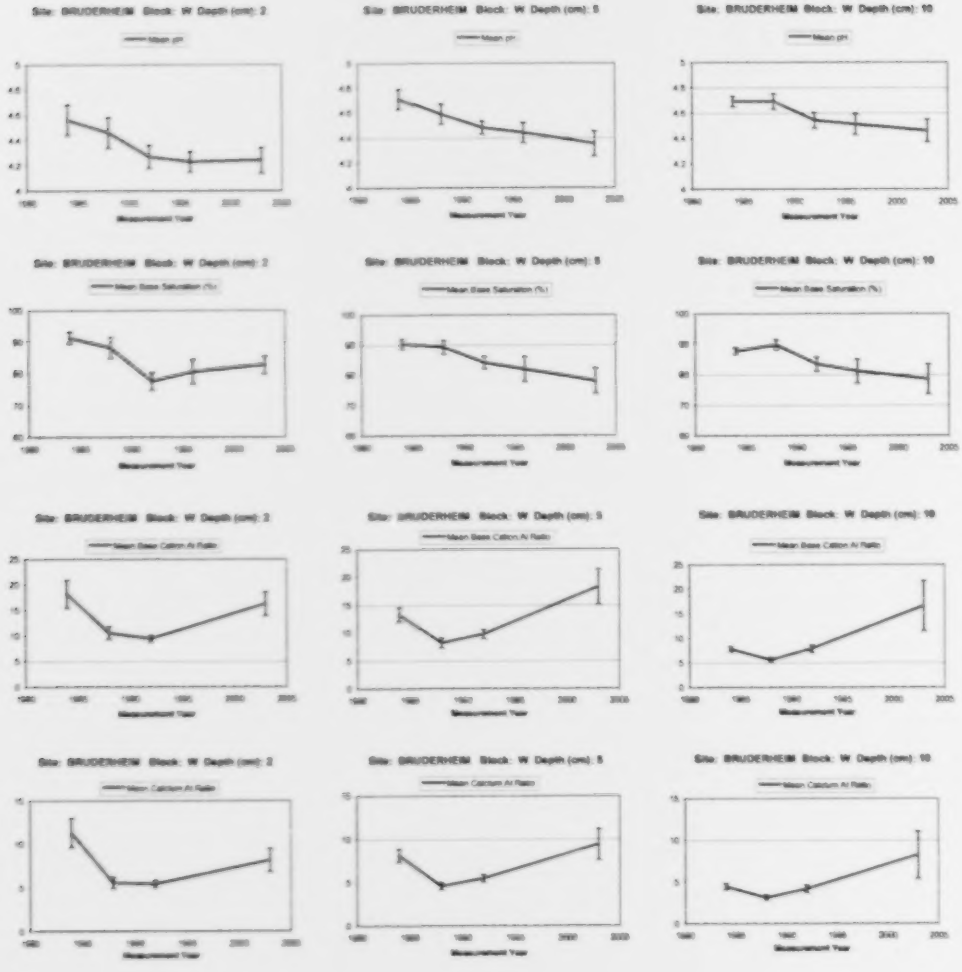
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
BRUDERHEIM	W	2	1984	4.56	0.12	0.41	12
BRUDERHEIM	W	2	1988	4.46	0.12	0.43	12
BRUDERHEIM	W	2	1992	4.27	0.09	0.32	12
BRUDERHEIM	W	2	1996	4.23	0.08	0.29	12
BRUDERHEIM	W	2	2003	4.24	0.1	0.33	12
BRUDERHEIM	W	5	1984	4.71	0.08	0.26	12
BRUDERHEIM	W	5	1988	4.59	0.08	0.28	12
BRUDERHEIM	W	5	1992	4.48	0.05	0.19	12
BRUDERHEIM	W	5	1996	4.44	0.08	0.27	12
BRUDERHEIM	W	5	2003	4.35	0.1	0.33	12
BRUDERHEIM	W	10	1984	4.69	0.04	0.15	12
BRUDERHEIM	W	10	1988	4.69	0.06	0.22	12
BRUDERHEIM	W	10	1992	4.54	0.06	0.2	12
BRUDERHEIM	W	10	1996	4.51	0.08	0.27	12
BRUDERHEIM	W	10	2003	4.46	0.09	0.31	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
BRUDERHEIM	W	2	1984	91.3	1.85	6.41	12
BRUDERHEIM	W	2	1988	88.13	3.34	11.57	12
BRUDERHEIM	W	2	1992	77.61	2.65	9.17	12
BRUDERHEIM	W	2	1996	80.61	3.83	13.25	12
BRUDERHEIM	W	2	2003	82.69	2.73	9.46	12
BRUDERHEIM	W	5	1984	90.25	1.59	5.51	12
BRUDERHEIM	W	5	1988	89.21	2.31	7.99	12
BRUDERHEIM	W	5	1992	84.08	2.01	6.97	12
BRUDERHEIM	W	5	1996	81.92	4.1	14.19	12
BRUDERHEIM	W	5	2003	77.98	4.12	14.26	12
BRUDERHEIM	W	10	1984	87.61	1.04	3.59	12
BRUDERHEIM	W	10	1988	89.73	1.68	5.82	12
BRUDERHEIM	W	10	1992	83.34	2.31	8.02	12
BRUDERHEIM	W	10	1996	81.08	3.94	13.64	12
BRUDERHEIM	W	10	2003	78.49	4.86	16.85	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
BRUDERHEIM	W	2	1984	18.15	2.72	9.43	12
BRUDERHEIM	W	2	1988	10.54	1.23	4.28	12
BRUDERHEIM	W	2	1992	9.37	0.61	2.1	12
BRUDERHEIM	W	2	2003	16.2	2.31	7.99	12
BRUDERHEIM	W	5	1984	13.25	1.27	4.38	12
BRUDERHEIM	W	5	1988	8.16	0.84	2.91	12
BRUDERHEIM	W	5	1992	9.71	0.75	2.61	12
BRUDERHEIM	W	5	2003	18.21	3.17	10.97	12
BRUDERHEIM	W	10	1984	7.73	0.53	1.83	12
BRUDERHEIM	W	10	1988	5.54	0.51	1.78	12
BRUDERHEIM	W	10	1992	7.79	0.7	2.41	12
BRUDERHEIM	W	10	2003	16.52	5.11	17.71	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
BRUDERHEIM	W	2	1984	11.28	1.68	5.84	12
BRUDERHEIM	W	2	1988	5.55	0.63	2.19	12
BRUDERHEIM	W	2	1992	5.39	0.39	1.35	12
BRUDERHEIM	W	2	2003	8.14	1.31	4.55	12
BRUDERHEIM	W	5	1984	8.09	0.75	2.59	12
BRUDERHEIM	W	5	1988	4.55	0.39	1.34	12
BRUDERHEIM	W	5	1992	5.46	0.4	1.39	12
BRUDERHEIM	W	5	2003	9.39	1.79	6.19	12
BRUDERHEIM	W	10	1984	4.41	0.35	1.21	12
BRUDERHEIM	W	10	1988	3.07	0.29	1.01	12
BRUDERHEIM	W	10	1992	4.11	0.43	1.49	12
BRUDERHEIM	W	10	2003	8.18	2.85	9.87	12

Figure 1 Soil acidity indicator summary: Bruderheim west block



Vertical bars represent standard error of the mean.

Table 2 Soil acidity indicator summary: Cold Lake east block (depths in cm)

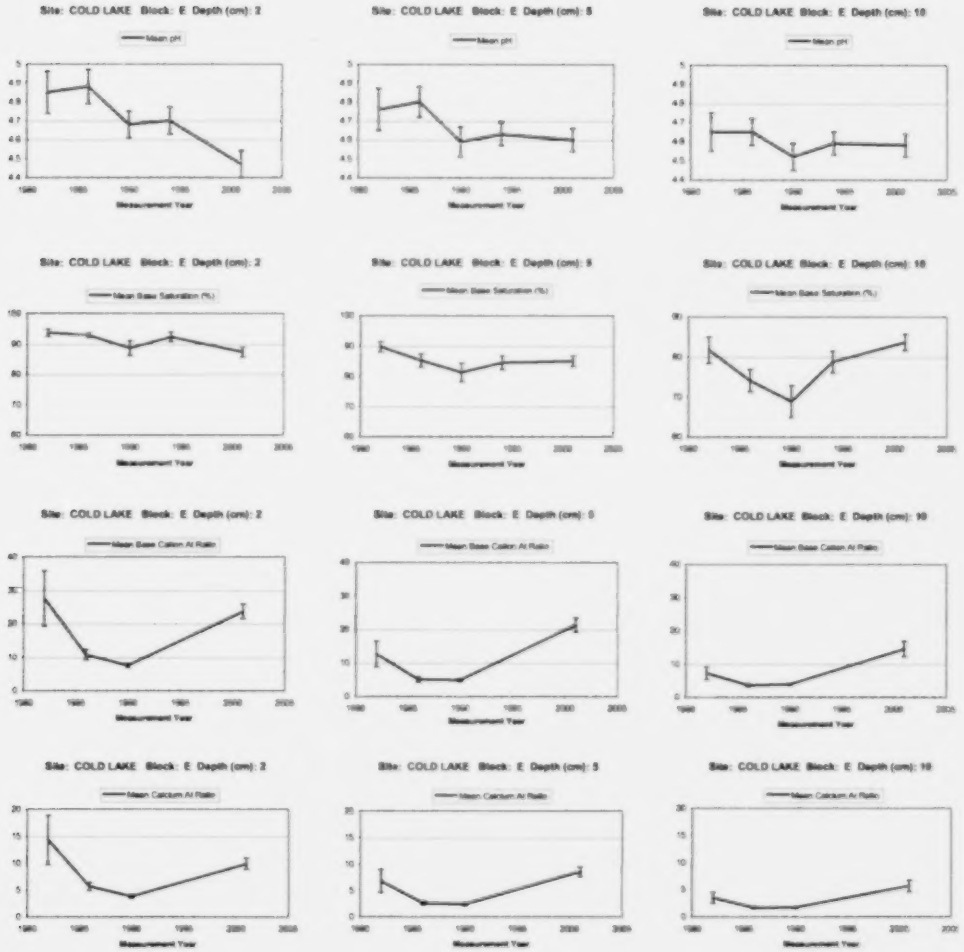
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
COLD LAKE	E	2	1982	4.85	0.11	0.38	12
COLD LAKE	E	2	1986	4.88	0.09	0.32	12
COLD LAKE	E	2	1990	4.68	0.07	0.23	12
COLD LAKE	E	2	1994	4.7	0.07	0.25	12
COLD LAKE	E	2	2001	4.47	0.07	0.23	12
COLD LAKE	E	5	1982	4.76	0.11	0.39	12
COLD LAKE	E	5	1986	4.8	0.08	0.29	12
COLD LAKE	E	5	1990	4.59	0.08	0.27	12
COLD LAKE	E	5	1994	4.63	0.06	0.21	12
COLD LAKE	E	5	2001	4.6	0.06	0.2	12
COLD LAKE	E	10	1982	4.65	0.1	0.34	12
COLD LAKE	E	10	1986	4.65	0.07	0.23	12
COLD LAKE	E	10	1990	4.52	0.07	0.24	12
COLD LAKE	E	10	1994	4.59	0.06	0.22	12
COLD LAKE	E	10	2001	4.58	0.06	0.2	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
COLD LAKE	E	2	1982	93.84	1.19	4.12	12
COLD LAKE	E	2	1986	92.94	0.82	2.83	12
COLD LAKE	E	2	1990	88.65	2.41	8.36	12
COLD LAKE	E	2	1994	92.37	1.57	5.42	12
COLD LAKE	E	2	2001	87.42	1.57	5.43	12
COLD LAKE	E	5	1982	89.78	1.69	5.87	12
COLD LAKE	E	5	1986	85.27	2.15	7.46	12
COLD LAKE	E	5	1990	81.34	3	10.41	12
COLD LAKE	E	5	1994	84.57	2.3	7.96	12
COLD LAKE	E	5	2001	85.05	1.74	6.03	12
COLD LAKE	E	10	1982	81.66	3.28	11.35	12
COLD LAKE	E	10	1986	74.02	2.79	9.67	12
COLD LAKE	E	10	1990	68.81	3.98	13.77	12
COLD LAKE	E	10	1994	78.7	2.72	9.44	12
COLD LAKE	E	10	2001	83.61	2.01	6.95	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
COLD LAKE	E	2	1982	27.58	8.27	27.42	11
COLD LAKE	E	2	1986	10.78	1.48	5.11	12
COLD LAKE	E	2	1990	7.55	0.62	2.16	12
COLD LAKE	E	2	2001	23.73	2.21	7.67	12
COLD LAKE	E	5	1982	12.64	3.82	13.25	12
COLD LAKE	E	5	1986	5.04	0.74	2.56	12
COLD LAKE	E	5	1990	4.87	0.43	1.49	12
COLD LAKE	E	5	2001	21.35	2.09	7.26	12
COLD LAKE	E	10	1982	7.18	1.94	6.74	12
COLD LAKE	E	10	1986	3.53	0.44	1.53	12
COLD LAKE	E	10	1990	3.84	0.25	0.87	12
COLD LAKE	E	10	2001	14.49	2.27	7.85	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
COLD LAKE	E	2	1982	14.32	4.57	15.15	11
COLD LAKE	E	2	1986	5.65	0.73	2.55	12
COLD LAKE	E	2	1990	3.8	0.32	1.11	12
COLD LAKE	E	2	2001	9.87	1.02	3.54	12
COLD LAKE	E	5	1982	6.72	2.14	7.41	12
COLD LAKE	E	5	1986	2.6	0.37	1.29	12
COLD LAKE	E	5	1990	2.35	0.23	0.8	12
COLD LAKE	E	5	2001	8.58	0.89	3.07	12
COLD LAKE	E	10	1982	3.47	0.96	3.33	12
COLD LAKE	E	10	1986	1.64	0.18	0.63	12
COLD LAKE	E	10	1990	1.67	0.16	0.57	12
COLD LAKE	E	10	2001	5.64	1.04	3.6	12

Figure 2 Soil acidity indicator summary: Cold Lake east block



Vertical bars represent standard error of the mean

Table 3 Soil acidity indicator summary: Devon north block (depths in cm)

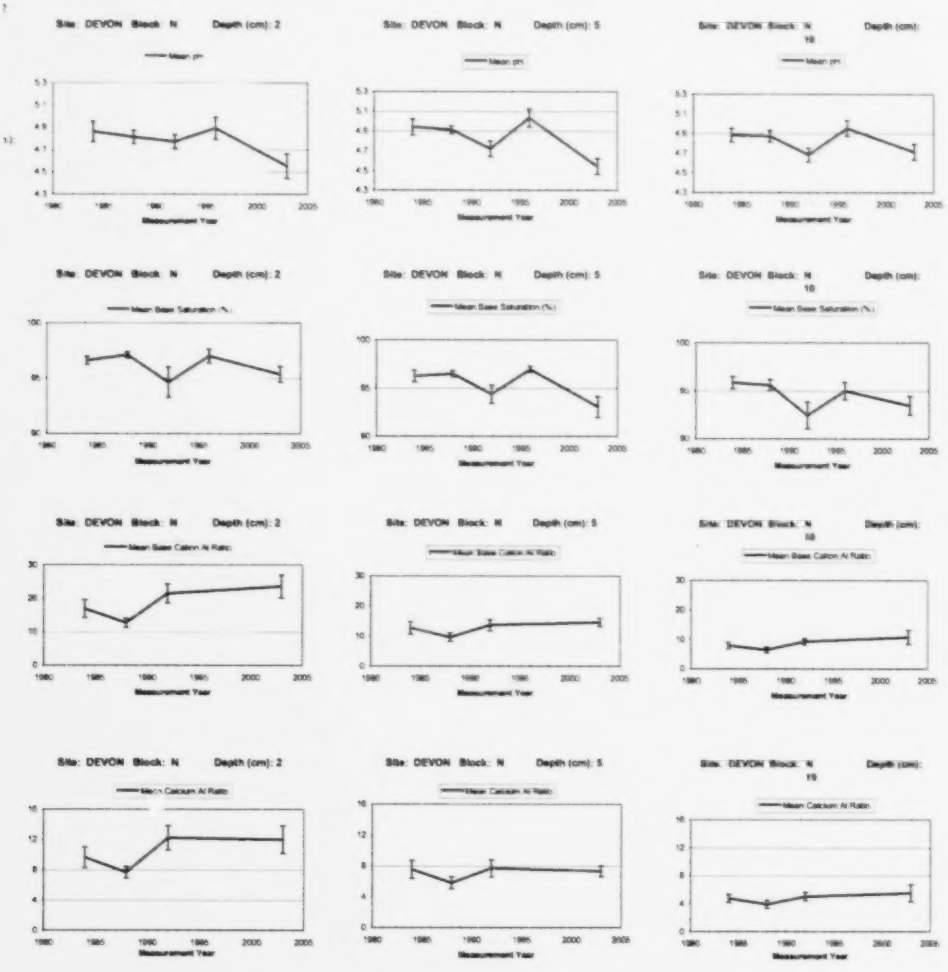
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
DEVON	N	2	1984	4.86	0.09	0.32	12
DEVON	N	2	1988	4.81	0.06	0.21	12
DEVON	N	2	1992	4.77	0.06	0.22	12
DEVON	N	2	1996	4.89	0.1	0.34	12
DEVON	N	2	2003	4.55	0.11	0.37	12
DEVON	N	5	1984	4.94	0.08	0.28	12
DEVON	N	5	1988	4.91	0.04	0.15	12
DEVON	N	5	1992	4.72	0.08	0.27	12
DEVON	N	5	1996	5.03	0.09	0.3	12
DEVON	N	5	2003	4.54	0.08	0.26	12
DEVON	N	10	1984	4.88	0.07	0.24	12
DEVON	N	10	1988	4.87	0.06	0.21	12
DEVON	N	10	1992	4.68	0.07	0.25	12
DEVON	N	10	1996	4.95	0.08	0.29	12
DEVON	N	10	2003	4.71	0.08	0.28	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
DEVON	N	2	1984	96.6	0.37	1.29	12
DEVON	N	2	1988	97.08	0.28	0.96	12
DEVON	N	2	1992	94.63	1.36	4.71	12
DEVON	N	2	1996	97	0.62	2.15	12
DEVON	N	2	2003	95.35	0.7	2.41	12
DEVON	N	5	1984	96.26	0.6	2.09	12
DEVON	N	5	1988	96.49	0.33	1.16	12
DEVON	N	5	1992	94.37	0.95	3.29	12
DEVON	N	5	1996	96.95	0.32	1.09	12
DEVON	N	5	2003	93.05	1.08	3.73	12
DEVON	N	10	1984	95.85	0.64	2.21	12
DEVON	N	10	1988	95.57	0.58	2.02	12
DEVON	N	10	1992	92.44	1.39	4.83	12
DEVON	N	10	1996	94.97	0.9	3.13	12
DEVON	N	10	2003	93.45	0.96	3.32	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
DEVON	N	2	1984	16.89	2.7	9.37	12
DEVON	N	2	1988	12.67	1.31	4.54	12
DEVON	N	2	1992	21.46	2.86	9.9	12
DEVON	N	2	2003	23.61	3.43	11.88	12
DEVON	N	5	1984	12.67	2.07	7.16	12
DEVON	N	5	1988	9.59	1.35	4.67	12
DEVON	N	5	1992	13.59	1.84	6.37	12
DEVON	N	5	2003	14.53	1.3	4.5	12
DEVON	N	10	1984	7.84	1.08	3.76	12
DEVON	N	10	1988	6.36	0.92	3.19	12
DEVON	N	10	1992	9.19	1	3.46	12
DEVON	N	10	2003	10.73	2.39	8.29	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
DEVON	N	2	1984	9.62	1.37	4.76	12
DEVON	N	2	1988	7.66	0.77	2.67	12
DEVON	N	2	1992	12.22	1.59	5.52	12
DEVON	N	2	2003	11.99	1.82	6.3	12
DEVON	N	5	1984	7.55	1.14	3.94	12
DEVON	N	5	1988	5.79	0.76	2.64	12
DEVON	N	5	1992	7.67	1.08	3.73	12
DEVON	N	5	2003	7.31	0.67	2.34	12
DEVON	N	10	1984	4.73	0.59	2.05	12
DEVON	N	10	1988	3.88	0.55	1.89	12
DEVON	N	10	1992	5	0.59	2.04	12
DEVON	N	10	2003	5.5	1.2	4.15	12

Figure 3 Soil acidity indicator summary: Devon north block



Vertical bars represent standard error of the mean.

Table 4 Soil acidity indicator summary: Esther north block (depths in cm)

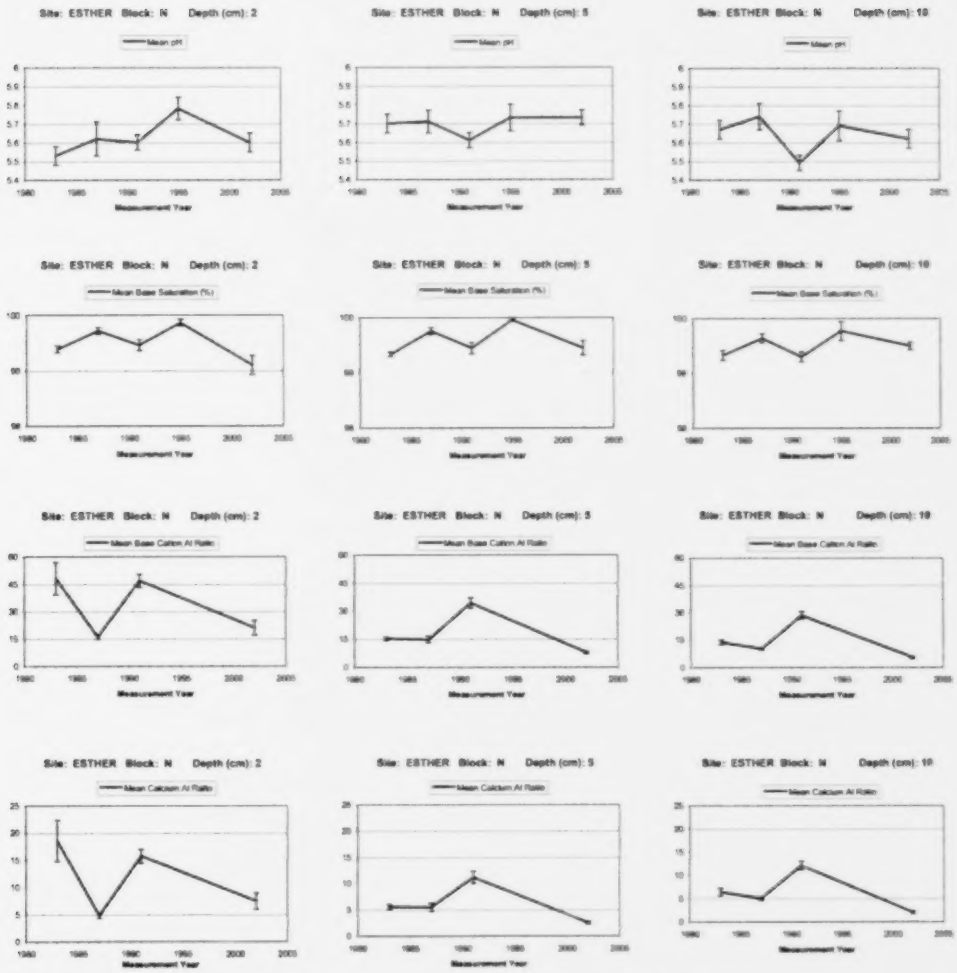
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
ESTHER	N	2	1983	5.53	0.05	0.16	12
ESTHER	N	2	1987	5.62	0.09	0.33	12
ESTHER	N	2	1991	5.6	0.04	0.13	12
ESTHER	N	2	1995	5.78	0.06	0.2	12
ESTHER	N	2	2002	5.6	0.05	0.19	12
ESTHER	N	5	1983	5.7	0.05	0.17	12
ESTHER	N	5	1987	5.71	0.06	0.21	12
ESTHER	N	5	1991	5.61	0.04	0.13	12
ESTHER	N	5	1995	5.73	0.07	0.23	12
ESTHER	N	5	2002	5.73	0.04	0.12	12
ESTHER	N	10	1983	5.67	0.05	0.18	12
ESTHER	N	10	1987	5.74	0.07	0.24	12
ESTHER	N	10	1991	5.49	0.04	0.13	12
ESTHER	N	10	1995	5.69	0.08	0.29	12
ESTHER	N	10	2002	5.62	0.05	0.16	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
ESTHER	N	2	1983	99.39	0.06	0.21	12
ESTHER	N	2	1987	99.72	0.06	0.19	12
ESTHER	N	2	1991	99.46	0.1	0.33	12
ESTHER	N	2	1995	99.87	0.06	0.22	12
ESTHER	N	2	2002	99.1	0.17	0.57	12
ESTHER	N	5	1983	99.34	0.04	0.15	12
ESTHER	N	5	1987	99.76	0.06	0.2	12
ESTHER	N	5	1991	99.45	0.1	0.36	12
ESTHER	N	5	1995	99.96	0.02	0.06	12
ESTHER	N	5	2002	99.45	0.13	0.47	12
ESTHER	N	10	1983	99.33	0.09	0.32	12
ESTHER	N	10	1987	99.64	0.08	0.27	12
ESTHER	N	10	1991	99.3	0.09	0.3	12
ESTHER	N	10	1995	99.77	0.17	0.58	12
ESTHER	N	10	2002	99.5	0.07	0.23	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
ESTHER	N	2	1983	48.2	8.77	30.37	12
ESTHER	N	2	1987	16.02	1.18	4.09	12
ESTHER	N	2	1991	46.85	3.6	12.48	12
ESTHER	N	2	2002	21.05	3.98	13.79	12
ESTHER	N	5	1983	15.24	0.9	3.1	12
ESTHER	N	5	1987	14.84	1.65	5.7	12
ESTHER	N	5	1991	34.36	2.73	9.45	12
ESTHER	N	5	2002	7.78	0.72	2.48	12
ESTHER	N	10	1983	13.74	1.24	4.29	12
ESTHER	N	10	1987	10.26	0.69	2.4	12
ESTHER	N	10	1991	28.49	1.98	6.87	12
ESTHER	N	10	2002	5.42	0.64	2.22	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
ESTHER	N	2	1983	18.56	3.81	13.18	12
ESTHER	N	2	1987	4.8	0.48	1.67	12
ESTHER	N	2	1991	15.77	1.27	4.41	12
ESTHER	N	2	2002	7.46	1.48	5.14	12
ESTHER	N	5	1983	5.56	0.46	1.61	12
ESTHER	N	5	1987	5.52	0.75	2.61	12
ESTHER	N	5	1991	11.19	1.13	3.9	12
ESTHER	N	5	2002	2.54	0.3	1.05	12
ESTHER	N	10	1983	6.41	0.74	2.58	12
ESTHER	N	10	1987	5.01	0.37	1.28	12
ESTHER	N	10	1991	12.14	0.88	3.07	12
ESTHER	N	10	2002	2.05	0.27	0.92	12

Figure 4 Soil acidity indicator summary: Esther north block


Site: ESTHER Block: N Depth (cm): 2
Site: ESTHER Block: N Depth (cm): 5
Site: ESTHER Block: N Depth (cm): 10
Mean pH
Site: ESTHER Block: N Depth (cm): 2
Site: ESTHER Block: N Depth (cm): 5
Site: ESTHER Block: N Depth (cm): 10
Mean Base Saturation (%)
Site: ESTHER Block: N Depth (cm): 2
Site: ESTHER Block: N Depth (cm): 5
Site: ESTHER Block: N Depth (cm): 10
Mean Base Cation Al Ratio
Site: ESTHER Block: N Depth (cm): 2
Site: ESTHER Block: N Depth (cm): 5
Site: ESTHER Block: N Depth (cm): 10
Mean Calcium Al Ratio
Measurement Year

Vertical bars represent standard error of the mean.

Table 5 Soil acidity indicator summary: Fort McMurray north block (depths in cm)

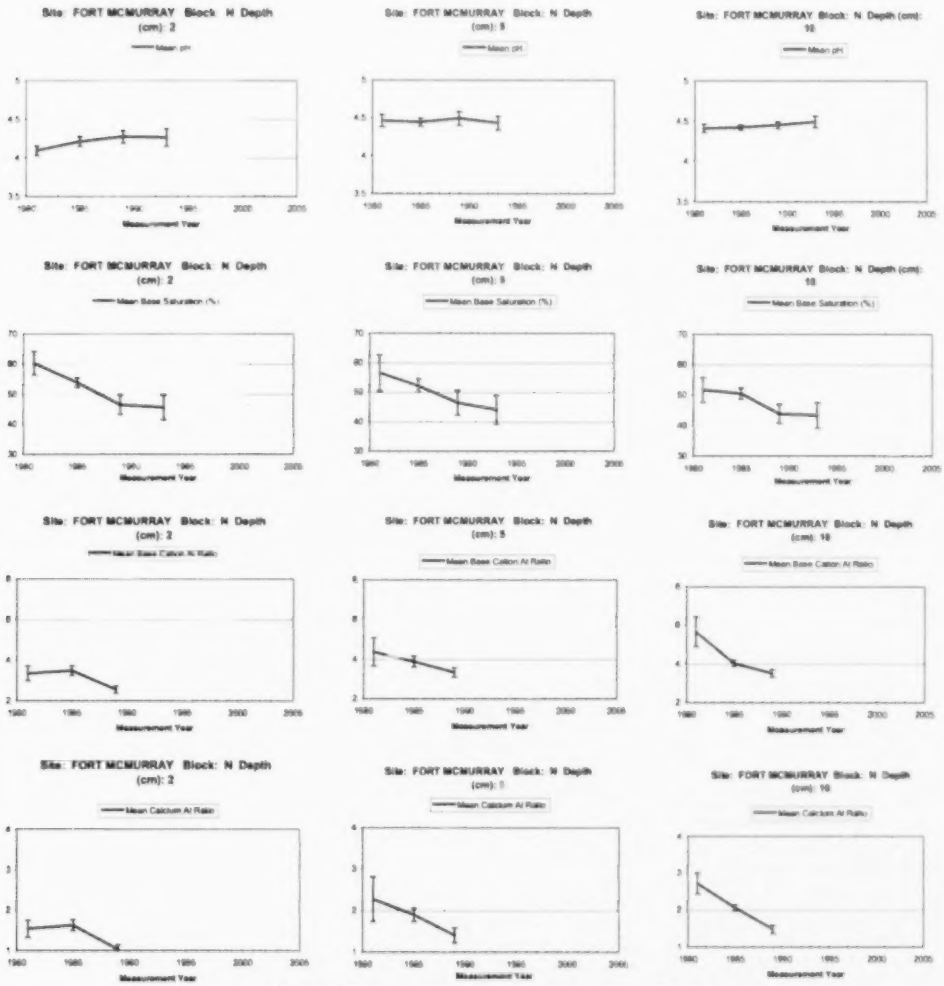
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
FORT MCMURRAY	N	2	1981	4.09	0.06	0.22	12
FORT MCMURRAY	N	2	1985	4.21	0.06	0.19	12
FORT MCMURRAY	N	2	1989	4.27	0.08	0.26	12
FORT MCMURRAY	N	2	1993	4.26	0.11	0.39	12
FORT MCMURRAY	N	5	1981	4.46	0.08	0.26	12
FORT MCMURRAY	N	5	1985	4.44	0.05	0.18	12
FORT MCMURRAY	N	5	1989	4.49	0.09	0.3	12
FORT MCMURRAY	N	5	1993	4.43	0.09	0.31	12
FORT MCMURRAY	N	10	1981	4.41	0.05	0.17	12
FORT MCMURRAY	N	10	1985	4.42	0.03	0.11	12
FORT MCMURRAY	N	10	1989	4.45	0.04	0.13	12
FORT MCMURRAY	N	10	1993	4.49	0.07	0.25	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
FORT MCMURRAY	N	2	1981	60.26	3.84	13.3	12
FORT MCMURRAY	N	2	1985	53.8	1.54	5.33	12
FORT MCMURRAY	N	2	1989	46.39	3.19	11.06	12
FORT MCMURRAY	N	2	1993	45.53	4.08	14.14	12
FORT MCMURRAY	N	5	1981	56.48	6.13	21.22	12
FORT MCMURRAY	N	5	1985	52.2	2.26	7.83	12
FORT MCMURRAY	N	5	1989	46.38	4.17	14.44	12
FORT MCMURRAY	N	5	1993	44.02	4.85	16.79	12
FORT MCMURRAY	N	10	1981	51.68	4.07	14.1	12
FORT MCMURRAY	N	10	1985	50.48	1.81	6.27	12
FORT MCMURRAY	N	10	1989	43.86	3.06	10.59	12
FORT MCMURRAY	N	10	1993	43.3	4.16	14.41	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
FORT MCMURRAY	N	2	1981	3.34	0.36	1.24	12
FORT MCMURRAY	N	2	1985	3.48	0.23	0.81	12
FORT MCMURRAY	N	2	1989	2.55	0.17	0.57	12
FORT MCMURRAY	N	5	1981	4.36	0.71	2.46	12
FORT MCMURRAY	N	5	1985	3.87	0.27	0.93	12
FORT MCMURRAY	N	5	1989	3.32	0.22	0.76	12
FORT MCMURRAY	N	10	1981	5.65	0.77	2.65	12
FORT MCMURRAY	N	10	1985	4.02	0.16	0.54	12
FORT MCMURRAY	N	10	1989	3.5	0.18	0.64	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
FORT MCMURRAY	N	2	1981	1.54	0.21	0.72	12
FORT MCMURRAY	N	2	1985	1.63	0.13	0.44	12
FORT MCMURRAY	N	2	1989	1.03	0.11	0.39	12
FORT MCMURRAY	N	5	1981	2.27	0.54	1.86	12
FORT MCMURRAY	N	5	1985	1.89	0.16	0.57	12
FORT MCMURRAY	N	5	1989	1.4	0.18	0.61	12
FORT MCMURRAY	N	10	1981	2.71	0.28	0.96	12
FORT MCMURRAY	N	10	1985	2.05	0.08	0.26	12
FORT MCMURRAY	N	10	1989	1.47	0.11	0.39	12

Figure 5 Soil acidity indicator summary: Fort McMurray north block


Site: FORT MCMURRAY Block: N Depth (cm): 2
Site: FORT MCMURRAY Block: N Depth (cm): 5
Site: FORT MCMURRAY Block: N Depth (cm): 10
Mean pH
Mean Base Saturation (%)
Mean Base Cation:Al Ratio
Mean Calcium:Al Ratio
Measurement Year

Vertical bars represent standard error of the mean.

Table 6 Soil acidity indicator summary: High Prairie east block (depths in cm)

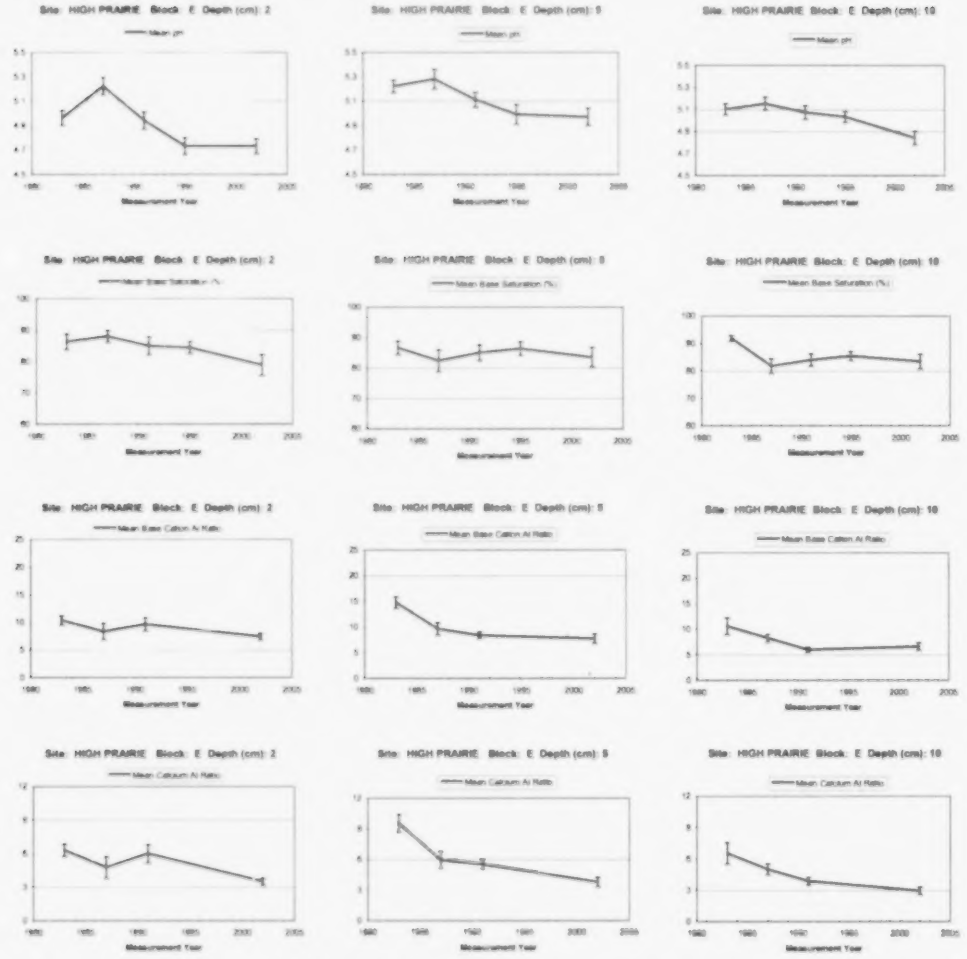
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
HIGH PRAIRIE	E	2	1983	4.96	0.06	0.2	12
HIGH PRAIRIE	E	2	1987	5.22	0.07	0.25	12
HIGH PRAIRIE	E	2	1991	4.94	0.07	0.24	12
HIGH PRAIRIE	E	2	1995	4.73	0.07	0.25	12
HIGH PRAIRIE	E	2	2002	4.73	0.06	0.21	12
HIGH PRAIRIE	E	5	1983	5.22	0.05	0.17	12
HIGH PRAIRIE	E	5	1987	5.28	0.08	0.27	12
HIGH PRAIRIE	E	5	1991	5.11	0.06	0.22	12
HIGH PRAIRIE	E	5	1995	4.99	0.08	0.27	12
HIGH PRAIRIE	E	5	2002	4.97	0.07	0.25	12
HIGH PRAIRIE	E	10	1983	5.1	0.05	0.17	12
HIGH PRAIRIE	E	10	1987	5.15	0.06	0.19	12
HIGH PRAIRIE	E	10	1991	5.07	0.06	0.21	12
HIGH PRAIRIE	E	10	1995	5.03	0.05	0.18	12
HIGH PRAIRIE	E	10	2002	4.84	0.06	0.2	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
HIGH PRAIRIE	E	2	1983	86.2	2.45	8.49	12
HIGH PRAIRIE	E	2	1987	87.92	1.88	6.53	12
HIGH PRAIRIE	E	2	1991	84.91	2.85	9.88	12
HIGH PRAIRIE	E	2	1995	84.32	1.88	6.51	12
HIGH PRAIRIE	E	2	2002	78.81	3.29	11.41	12
HIGH PRAIRIE	E	5	1983	86.53	2.2	7.63	12
HIGH PRAIRIE	E	5	1987	82.28	3.61	12.49	12
HIGH PRAIRIE	E	5	1991	84.89	2.55	8.84	12
HIGH PRAIRIE	E	5	1995	86.26	2.24	7.76	12
HIGH PRAIRIE	E	5	2002	83.43	3.2	11.09	12
HIGH PRAIRIE	E	10	1983	91.78	0.99	3.43	12
HIGH PRAIRIE	E	10	1987	81.66	2.59	8.97	12
HIGH PRAIRIE	E	10	1991	83.86	2.21	7.66	12
HIGH PRAIRIE	E	10	1995	85.29	1.6	5.54	12
HIGH PRAIRIE	E	10	2002	83.33	2.57	8.9	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
HIGH PRAIRIE	E	2	1983	10.28	0.82	2.86	12
HIGH PRAIRIE	E	2	1987	8.26	1.44	5	12
HIGH PRAIRIE	E	2	1991	9.57	1.15	3.98	12
HIGH PRAIRIE	E	2	2002	7.34	0.55	1.91	12
HIGH PRAIRIE	E	5	1983	14.71	1.08	3.74	12
HIGH PRAIRIE	E	5	1987	9.59	1.16	4.03	12
HIGH PRAIRIE	E	5	1991	8.34	0.64	2.23	12
HIGH PRAIRIE	E	5	2002	7.67	0.91	3.16	12
HIGH PRAIRIE	E	10	1983	10.51	1.62	5.61	12
HIGH PRAIRIE	E	10	1987	8.19	0.73	2.54	12
HIGH PRAIRIE	E	10	1991	5.91	0.48	1.67	12
HIGH PRAIRIE	E	10	2002	6.57	0.68	2.34	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
HIGH PRAIRIE	E	2	1983	6.26	0.54	1.87	12
HIGH PRAIRIE	E	2	1987	4.73	0.95	3.3	12
HIGH PRAIRIE	E	2	1991	5.94	0.8	2.77	12
HIGH PRAIRIE	E	2	2002	3.45	0.3	1.05	12
HIGH PRAIRIE	E	5	1983	9.48	0.88	3.03	12
HIGH PRAIRIE	E	5	1987	5.9	0.81	2.82	12
HIGH PRAIRIE	E	5	1991	5.47	0.46	1.6	12
HIGH PRAIRIE	E	5	2002	3.73	0.46	1.58	12
HIGH PRAIRIE	E	10	1983	6.5	1.02	3.55	12
HIGH PRAIRIE	E	10	1987	4.97	0.51	1.77	12
HIGH PRAIRIE	E	10	1991	3.83	0.35	1.2	12
HIGH PRAIRIE	E	10	2002	2.9	0.36	1.25	12

Figure 6 Soil acidity indicator summary: High Prairie east block



Vertical bars represent standard error of the mean.

Table 7 Soil acidity indicator summary: Rocky Mountain House south block (depths in cm)

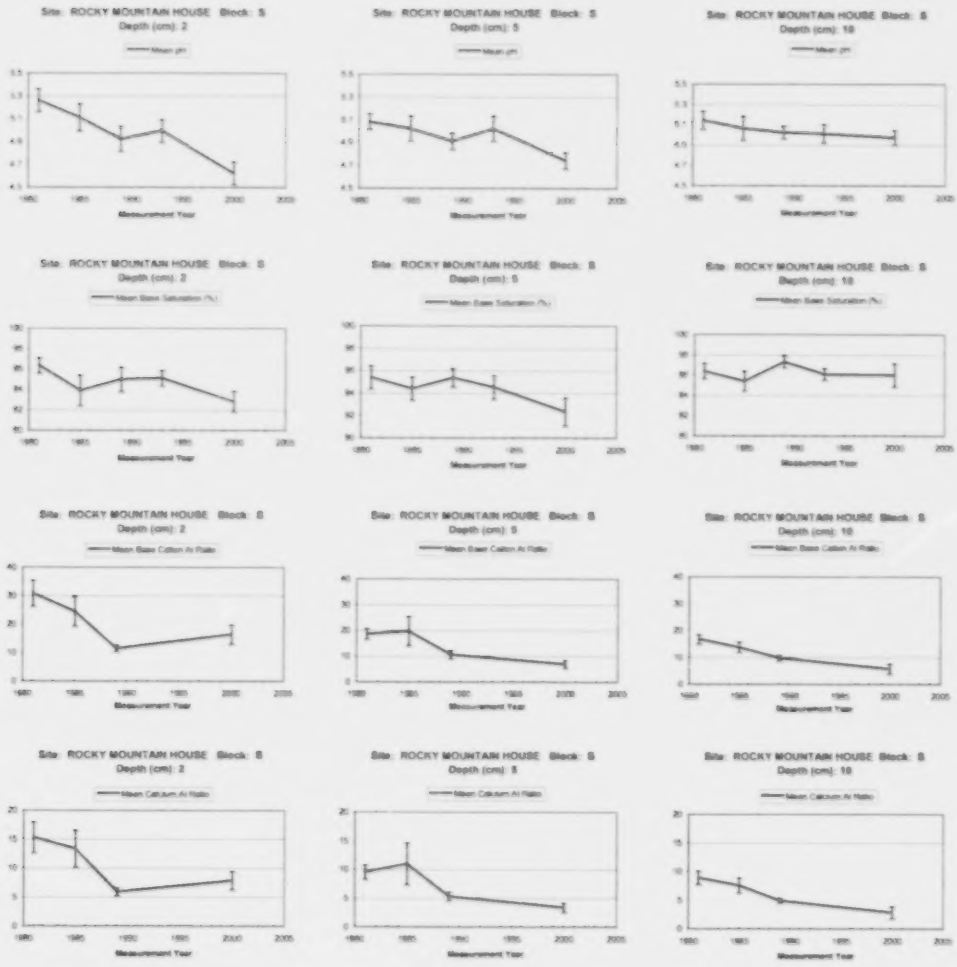
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
ROCKY MOUNTAIN HOUSE	S	2	1981	5.26	0.1	0.34	12
ROCKY MOUNTAIN HOUSE	S	2	1985	5.11	0.12	0.42	12
ROCKY MOUNTAIN HOUSE	S	2	1989	4.92	0.11	0.39	12
ROCKY MOUNTAIN HOUSE	S	2	1993	4.99	0.1	0.33	12
ROCKY MOUNTAIN HOUSE	S	2	2000	4.62	0.1	0.34	12
ROCKY MOUNTAIN HOUSE	S	5	1981	5.08	0.07	0.25	12
ROCKY MOUNTAIN HOUSE	S	5	1985	5.02	0.11	0.38	12
ROCKY MOUNTAIN HOUSE	S	5	1989	4.91	0.07	0.25	12
ROCKY MOUNTAIN HOUSE	S	5	1993	5.02	0.11	0.37	12
ROCKY MOUNTAIN HOUSE	S	5	2000	4.74	0.07	0.25	12
ROCKY MOUNTAIN HOUSE	S	10	1981	5.14	0.09	0.31	12
ROCKY MOUNTAIN HOUSE	S	10	1985	5.06	0.12	0.43	12
ROCKY MOUNTAIN HOUSE	S	10	1989	5.02	0.06	0.21	12
ROCKY MOUNTAIN HOUSE	S	10	1993	5.01	0.09	0.32	12
ROCKY MOUNTAIN HOUSE	S	10	2000	4.97	0.07	0.24	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
ROCKY MOUNTAIN HOUSE	S	2	1981	96.32	0.76	2.64	12
ROCKY MOUNTAIN HOUSE	S	2	1985	93.86	1.5	5.21	12
ROCKY MOUNTAIN HOUSE	S	2	1989	94.95	1.19	4.12	12
ROCKY MOUNTAIN HOUSE	S	2	1993	95.07	0.75	2.59	12
ROCKY MOUNTAIN HOUSE	S	2	2000	92.78	1.01	3.49	12
ROCKY MOUNTAIN HOUSE	S	5	1981	95.38	1.02	3.54	12
ROCKY MOUNTAIN HOUSE	S	5	1985	94.38	1.03	3.56	12
ROCKY MOUNTAIN HOUSE	S	5	1989	95.34	0.83	2.87	12
ROCKY MOUNTAIN HOUSE	S	5	1993	94.5	1.04	3.6	12
ROCKY MOUNTAIN HOUSE	S	5	2000	92.31	1.25	4.33	12
ROCKY MOUNTAIN HOUSE	S	10	1981	96.37	0.75	2.59	12
ROCKY MOUNTAIN HOUSE	S	10	1985	95.38	0.98	3.4	12
ROCKY MOUNTAIN HOUSE	S	10	1989	97.28	0.59	2.03	12
ROCKY MOUNTAIN HOUSE	S	10	1993	96.04	0.57	1.99	12
ROCKY MOUNTAIN HOUSE	S	10	2000	95.96	1.14	3.94	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
ROCKY MOUNTAIN HOUSE	S	2	1981	30.69	4.56	15.78	12
ROCKY MOUNTAIN HOUSE	S	2	1985	24.33	5.16	17.86	12
ROCKY MOUNTAIN HOUSE	S	2	1989	11.36	1.09	3.77	12
ROCKY MOUNTAIN HOUSE	S	2	2000	16.32	3.35	11.6	12
ROCKY MOUNTAIN HOUSE	S	5	1981	18.5	1.99	6.88	12
ROCKY MOUNTAIN HOUSE	S	5	1985	19.52	5.63	19.52	12
ROCKY MOUNTAIN HOUSE	S	5	1989	10.45	1.55	5.36	12
ROCKY MOUNTAIN HOUSE	S	5	2000	6.79	1.41	4.87	12
ROCKY MOUNTAIN HOUSE	S	10	1981	16.64	1.68	5.81	12
ROCKY MOUNTAIN HOUSE	S	10	1985	13.67	1.91	6.61	12
ROCKY MOUNTAIN HOUSE	S	10	1989	9.63	1.03	3.56	12
ROCKY MOUNTAIN HOUSE	S	10	2000	5.59	1.8	6.23	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
ROCKY MOUNTAIN HOUSE	S	2	1981	15.22	2.67	9.23	12
ROCKY MOUNTAIN HOUSE	S	2	1985	13.25	3.18	11.01	12
ROCKY MOUNTAIN HOUSE	S	2	1989	5.77	0.68	2.35	12
ROCKY MOUNTAIN HOUSE	S	2	2000	7.77	1.61	5.57	12
ROCKY MOUNTAIN HOUSE	S	5	1981	9.45	1.22	4.22	12
ROCKY MOUNTAIN HOUSE	S	5	1985	10.89	3.64	12.6	12
ROCKY MOUNTAIN HOUSE	S	5	1989	5.22	0.74	2.56	12
ROCKY MOUNTAIN HOUSE	S	5	2000	3.27	0.78	2.71	12
ROCKY MOUNTAIN HOUSE	S	10	1981	8.85	1.17	4.05	12
ROCKY MOUNTAIN HOUSE	S	10	1985	7.5	1.31	4.54	12
ROCKY MOUNTAIN HOUSE	S	10	1989	4.82	0.4	1.39	12
ROCKY MOUNTAIN HOUSE	S	10	2000	2.75	1.05	3.63	12

Figure 7 **Soil acidity indicator summary: Rocky Mountain House south block**



Vertical bars represent standard error of the mean.

Table 8 Soil acidity indicator summary: Twin Butte west block (depths in cm)

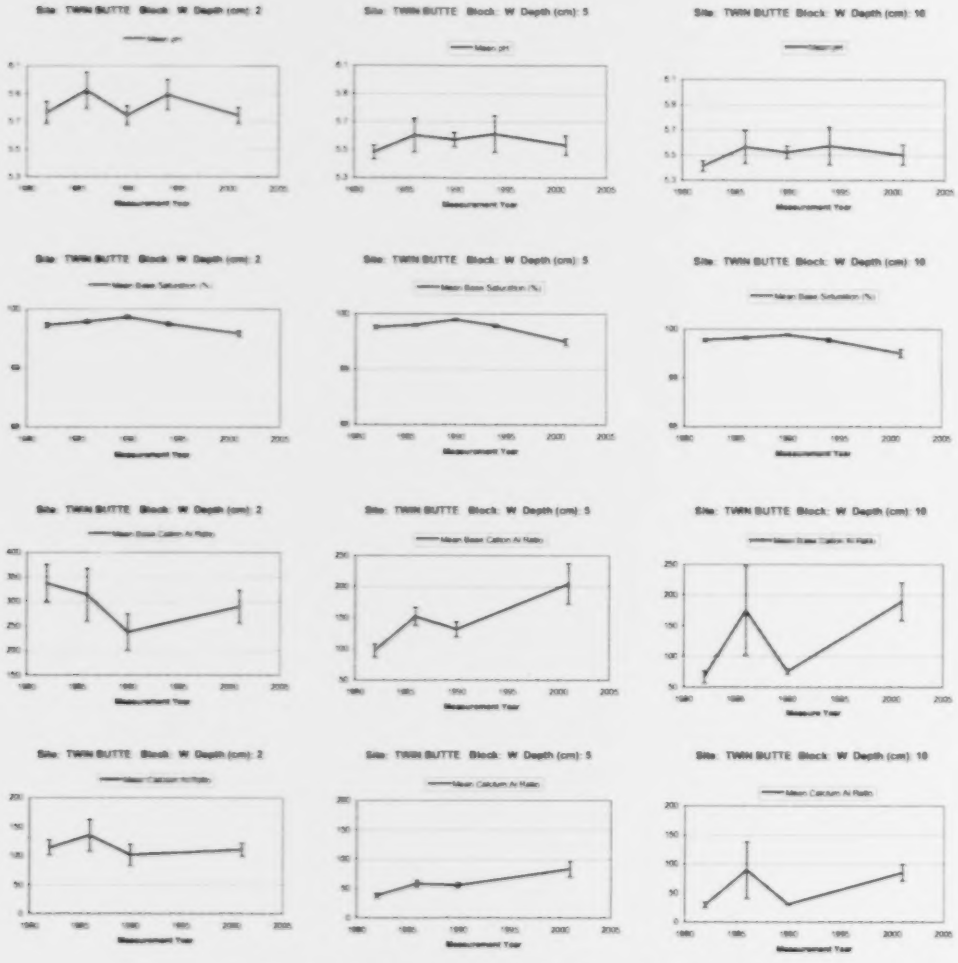
Site	Block	Depth	Year	Mean pH	stderr	std	Numb_OBS
TWIN BUTTE	W	2	1982	5.76	0.08	0.26	12
TWIN BUTTE	W	2	1986	5.92	0.13	0.44	12
TWIN BUTTE	W	2	1990	5.74	0.07	0.25	12
TWIN BUTTE	W	2	1994	5.89	0.11	0.37	12
TWIN BUTTE	W	2	2001	5.74	0.06	0.21	12
TWIN BUTTE	W	5	1982	5.48	0.05	0.18	12
TWIN BUTTE	W	5	1986	5.6	0.12	0.43	12
TWIN BUTTE	W	5	1990	5.57	0.05	0.18	12
TWIN BUTTE	W	5	1994	5.61	0.13	0.47	12
TWIN BUTTE	W	5	2001	5.53	0.07	0.25	12
TWIN BUTTE	W	10	1982	5.41	0.04	0.13	12
TWIN BUTTE	W	10	1986	5.56	0.13	0.46	12
TWIN BUTTE	W	10	1990	5.52	0.05	0.17	12
TWIN BUTTE	W	10	1994	5.57	0.15	0.51	12
TWIN BUTTE	W	10	2001	5.5	0.08	0.27	12

Site	Block	Depth	Year	Mean Base Saturation (%)	stderr	std	Numb_OBS
TWIN BUTTE	W	2	1982	99.72	0.04	0.13	12
TWIN BUTTE	W	2	1986	99.78	0.03	0.09	12
TWIN BUTTE	W	2	1990	99.86	0.03	0.12	12
TWIN BUTTE	W	2	1994	99.74	0.03	0.11	12
TWIN BUTTE	W	2	2001	99.58	0.05	0.16	12
TWIN BUTTE	W	5	1982	99.75	0.03	0.11	12
TWIN BUTTE	W	5	1986	99.79	0.02	0.08	12
TWIN BUTTE	W	5	1990	99.89	0.02	0.06	12
TWIN BUTTE	W	5	1994	99.78	0.03	0.09	12
TWIN BUTTE	W	5	2001	99.49	0.06	0.22	12
TWIN BUTTE	W	10	1982	99.77	0.03	0.1	12
TWIN BUTTE	W	10	1986	99.82	0.03	0.1	12
TWIN BUTTE	W	10	1990	99.88	0.02	0.07	12
TWIN BUTTE	W	10	1994	99.77	0.04	0.13	12
TWIN BUTTE	W	10	2001	99.5	0.08	0.28	12

Site	Block	Depth	Year	Mean Base Cation:Al Ratio	stderr	std	Numb_OBS
TWIN BUTTE	W	2	1982	335.91	39.18	135.65	12
TWIN BUTTE	W	2	1986	312.7	53.61	185.7	12
TWIN BUTTE	W	2	1990	236.61	37.26	129.09	12
TWIN BUTTE	W	2	2001	288.93	33.25	115.18	12
TWIN BUTTE	W	5	1982	96.57	10.43	36.12	12
TWIN BUTTE	W	5	1986	151.79	14.56	48.27	11
TWIN BUTTE	W	5	1990	130.73	11.93	41.33	12
TWIN BUTTE	W	5	2001	204.04	32.47	112.49	12
TWIN BUTTE	W	10	1982	86.21	9.63	33.36	12
TWIN BUTTE	W	10	1986	174.35	72.77	252.09	12
TWIN BUTTE	W	10	1990	74.77	3.89	13.49	12
TWIN BUTTE	W	10	2001	188.9	31	107.39	12

Site	Block	Depth	Year	Mean Calcium:Al Ratio	stderr	std	Numb_OBS
TWIN BUTTE	W	2	1982	113.4	13.06	45.24	12
TWIN BUTTE	W	2	1986	134.51	27.51	95.3	12
TWIN BUTTE	W	2	1990	100.82	18.23	63.15	12
TWIN BUTTE	W	2	2001	109.56	11.36	39.34	12
TWIN BUTTE	W	5	1982	37.33	3.65	12.65	12
TWIN BUTTE	W	5	1986	57.55	5.68	18.84	11
TWIN BUTTE	W	5	1990	54.51	4.48	15.53	12
TWIN BUTTE	W	5	2001	82.39	13.18	45.64	12
TWIN BUTTE	W	10	1982	28.99	4.55	15.77	12
TWIN BUTTE	W	10	1986	88.96	48.55	168.17	12
TWIN BUTTE	W	10	1990	30.04	1.43	4.96	12
TWIN BUTTE	W	10	2001	84.28	14.38	49.83	12

Figure 8 **Soil acidity indicator summary: Twin Butte west block**



Vertical bars represent standard error of the mean.

8.0 APPENDIX 2. SAS® code for data input, statistical analysis, and output to Excel®

```
**************************************************************************************
* Program Name: Excel data input and output for Acidity analysis
* Author: Frank Liu
* Create Date: Feb. 6, 2004
* Last Modify: March 2, 2004
* Usage:  Start MS Excel and open the data file
*       Read in data of each page and combine them together
*       Quick analysis of data
*       Statistics, Graphs, and outputs to Excel for final graphing
**************************************************************************************;

***********************************************
* Step One: Reading in data from Excel pages*
***********************************************;


          data  shetname;
              informat shetname $30.;
              input shetname $ 4-30;
            call symput('file'||put(_n_,1.), trim(shetname));
                  cards;
  Bruderheim
  Cold Lake
  Devon
  Esther
  Fort McMurray
  High Prairie
  Rocky Mtn House
  Twin Butte
run;

  data allfile; delete; run;

  %let i=1;  * change i from 1 to 8 to read all data;
   filename excel1 dde "excel|&&file&i.!r3c1:r1000c36" notab;
          %*let files=%cmpress(&&file&i);
    data files;
              newloc="&&file&i.";
     infile excel1 dlm='09'x dsd  missover   ;
            informat location $30.; length location $30;
   input LOCATION $ SITE $ REP $ PERIOD YEAR DEPTH    g h i j k l m n o p q
          r s t u v w x y z aa ab ac ad ae  ;
                keep location newloc site rep period year depth g aa ab ac ad ae;
*CACL2PH        BACL2CA         BACL2MG         BACL2NA         BACL2K BACL2FE $ BACL2MN;
*BACL2 AL       CA      MG      NA      K       FE      MN      AL      SO4     IC_SO4 PO4      EA
          CEC     BS      TKN     TS      TC      BS_1    BS_2    Ca_Al   BC_Al;;

data allfile; set allfile files (rename =(g=ph aa=bs ab=bs1 ac=bs2 ad=ca_al ae=bc_al));
  run;

 * Repeat above two data processes until all data read in completed;

* Some brief analysis of data;
```

```
proc freq; table newloc*location /norow nocol nopercent;
      run;

            proc plot data=allfile; plot ph*bs= site; by location;
         where location>' ';; run;

* Select blocks on each site for analysis - based on Dave D.'s email
                                other information is also included;

data analblk;
 informat location location $30.; length location $30;
 input  @1 Block $1-1 @3 mer 3-3 @5 twp 5-6 @8 rng 8-9  @11 nsn_num 11-12 @15 location $15-45;;
  call symput('file'||put(_n_,1.), trim(location));
  if nsn_num=1 then      eco_nsn='Central Mixedwood';
  else if nsn_num=2 then  eco_nsn='Dry Mixedwood';
  else if nsn_num=11 then eco_nsn='Lower Foothills';
  else if nsn_num=16 then eco_nsn='Central Parkland';
  else if nsn_num=13 then eco_nsn='Foothills Fescue';
  else if nsn_num=17 then eco_nsn='Dry Mixedgrass';
   township=compress(twp||'-'||rng||'-'||mer);
 cards;  * Changed on Feb. 25, Devon took North Block;
W 4 56 20 16  BRUDERHEIM
E 4 64 2  1   COLD LAKE
N 4 51 26 16  DEVON
N 4 31 2  17  ESTHER
N 4 93 9  1   FORT MCMURRAY
E 5 75 17 2   HIGH PRAIRIE
S 5 38 8  11  ROCKY MOUNTAIN HOUSE
W 4 5  29 13  TWIN BUTTE
;

 proc print ; var location block township eco_nsn; run;

 * The above print out will be used to produce Word table;

 * Sorting data for merging;

 proc sort data=allfile; by location block depth year;

   proc sort data=analblk; by location block;
   run;


 proc sql;
  create table foranaly
   as select a.*, b.block
    from allfile as a , analblk as b
    where a.location=b.location and a.site=b.block;



*****************************************
*   Step Two: Some initial analysis    *
*****************************************;


          * Some graphical analysis of relationships between different acidity indicators;
    * output them to
     ods rtf file='d:\temp\graph_output.rtf';
             ods listing close;
```

```
        proc plot data=foranaly vpercent=45 hpercent=45;
    plot bs*ph= depth  ;
                plot ca_al*ph=depth;
                 plot bc_al*ph=depth;
                        plot ca_al*bc_al=depth;
      by location;
    run;
                ods listing ; ods rtf close;

                data Bs_error;
                 set foranaly;
                  diff1=bs-bs1; diff2=bs-bs2;
      if abs(diff1)>5 or abs(diff2)>5; run;
ods listing close;
 ods html file='d:\temp\bs_error.html' style=minimal;
 options nodate nonumber;
                            proc print data=bs_error noobs;  title;
                             label location=site;
                              var location block year rep depth bs bs1 bs2 diff1 diff2;
        run;
ods html close;
 ods listing;


* Printing a few outliers and analysis;

 data check_outl; set foranaly;
   where location='TWIN BUTTE' and (year in (1989, 2001)) AND DEPTH=10;
run;

 PROC PRINT NOOBS; TITLE ORIGINIAL DATA SHOWING OUTLIERS EFFECT; RUN;
proc means mean stderr data=CHECK_OUTL noprint;
    var  bc_al ca_al  ;
          by location depth year; id block;
          output out=MEAN_OUTLI mean=
     stderr= stdr_bc_al stdr_ca_al
           std= std_bc_al std_ca_al
     n=pp_ratio ;
                where bc_al>.;
               run;

proc means mean stderr data=CHECK_OUTL noprint;
    var  bc_al ca_al  ;
          by location depth year; id block;
          output out=MEAN_REMV_OUTLI mean=
     stderr= stdr_bc_al stdr_ca_al
           std= std_bc_al std_ca_al
     n=pp_ratio ;
                where 300>bc_al>.;
               run;

               PROC PRINT DATA=MEAN_OUTLI; TITLE INCLUDING OUTLIER; RUN;
               PROC PRINT  ; TITLE AFTER REMOVING OUTLIER; RUN;

               * The printouts from above will be exported to Excel for graphing and tables;


********** Suggestion for future analysis
                - Using Univariate procedure to identify other outliers.
```

```
          - Regression between some acidity indicators and remove outliers using 3 times STD
                        - However, thess need to be done with caution
************;


proc freq; table newloc; where location=:' '; run;
proc freq data=allfile; table location site  /missing; run;
 proc print data=allfile (obs=5); run;

proc sort data=foranaly;
   by location depth year; where location>' ';
          run;

*****************************************
*    Step Three: Stats generation    *
*****************************************;


* with earlier version that analysis pH values by convert them back to proton conc.;

          data allfile2;set foranaly;
            ph_ion=10**(-ph);
             run;


 proc means mean stderr data=allfile2 noprint;
    var ph bs  ph_ion ;
            by location depth year; id block;
            output out=meanval1 mean=
      stderr=stdr_ph  stdr_bs stdr_ion
              std=std_ph std_bs   std_ion n=n_ph_bs ;
                    run;

 proc means mean stderr data=allfile2 noprint;
    var   bc_al ca_al   ;
            by location depth year; id block;
            output out=meanval2 mean=
      stderr= stdr_bc_al stdr_ca_al
              std= std_bc_al std_ca_al
      n=pp_ratio ;
                     where bc_al>.;
                    run;

                    proc transpose data=allfile2 out=tranph prefix=io;
                     by location depth year;
                      var ph_ion;
                      run;

data geoph;
 set tranph;
  geomean=(io1*io2*io3*io4*io5*io6*io7*io8*io9*io10*io11*io12)**(1/12);
          array io{*} io1-io12;
            geostd=0; geostderr=0;
           do i=1 to 12;
                geostd=geostd+(io{i}-geomean)**2;
                              end;
                               geostderr=sqrt(geostd/12);
                               geostd=sqrt(geostd);
          geo_ph=-log10(geomean);
           geo_std= geo_ph-(-log10(geostd+geomean));
```

```
          geo_stderr= geo_ph-(-log10(geostderr+geomean));
           keep location depth year geo_ph geo_std  geo_stderr;
run;


data meanval;
                    merge meanval1 geoph meanval2; by location depth year;
 ionph=-log10(ph_ion);
 stdrphion= ionph-(-log10(stdr_ion+ph_ion));
          diff_m=ph-ionph;
    diff_stdr=stdr_ph-stdrphion;
         run;

* Some printout to check the data;

proc print data=meanval;
 where abs(diff_m)>0.5 or abs(diff_stdr)>0.05;
var location depth year ph stdr_ph ionph stdrphion  geo_ph geo_std geo_stderr std_ph;
run;

proc plot; plot stdr_ph*stdrphion; run;
proc freq; table site; run;


*****************************************
*   data output to excel            *
*****************************************;

* Notes: - A new Excel file needs to be created with site location name included
       - Close the original data for protection
*      - Initial graphics and format need to be included to reduce extra work
           after data exports;

%let i=1;  * Repeat this a few times to get all data out;

FILENAME statres1 DDE "excel|Sheet&i!r2c1:r2c16" ;
FILENAME datas1 DDE "excel|&&file&i!r3c1:r18c16" notab;
FILENAME statres2 DDE "excel|Sheet&i!r20c1:r20c16" ;
FILENAME datas2 DDE "excel|&&file&i!r21c1:r38c16" notab;
FILENAME statres3 DDE "excel|&&file&i!r40c1:r40c16" ;
FILENAME datas3 DDE "excel|&&file&i!r41c1:r58c16" notab;
FILENAME statres4 DDE "excel|Sheet&i!r60c1:r60c16" ;
FILENAME datas4 DDE "excel|&&file&i!r61c1:r78c16" notab;
  DATA _NULL_;
   set &indata;
           format ph stdr_ph std_ph bs stdr_bs std_bs bc_al stdr_bc_al std_bc_al ca_al stdr_ca_al std_ca_al 6.2 ;

     file datas1   dlm='09'X ;
          put location block depth year ph stdr_ph std_ph n_ph_bs;

     file datas2   dlm='09'X ;
          put location block depth year   bs stdr_bs std_bs n_ph_bs;

     file datas3   dlm='09'X ;
          put location block depth year bc_al stdr_bc_al std_bc_al pp_ratio ;

     file datas4   dlm='09'X ;
          put location block depth year ca_al stdr_ca_al std_ca_al pp_ratio ;
/*
      file statres   dlm=',' ;
```

```
        put "Location Block Depth Year Ph, stderr, std, basal, stderr, std,  bc_al, stderr, std, ca_al, stderr, std,
Numbobs_ratio"  ;
      file datas   dlm='09'X ;
           put location block depth year ph stdr_ph std_ph bs stdr_bs std_bs bc_al stdr_bc_al std_bc_al ca_al
stdr_ca_al std_ca_al pp_ratio ;
*/
      where    location =  "%upcase(&&file&i)";
       * location=%uqout(')||&&file&i%uquote(');
   RUN;
```

9.0 Appendix 3. Influence of outliers on statistical calculations

Table 1. Ca:Al and base cation:Al outliers: Twin Butte west block, replicate "a"

LOCATION	BLOCK	REP	PERIOD	YEAR	DEPTH	ph	bs	bs1	bs2	ca_al	bc_al
TWIN BUTTE	W	A	2	1986	10	6.96	99.58	99.58	99.58	621	969
TWIN BUTTE	W	B	2	1986	10	5.23	99.873	99.87	99.87	29.1	108
TWIN BUTTE	W	C	2	1986	10	5.58	99.882	99.88	99.88	56.63	144
TWIN BUTTE	W	D	2	1986	10	5.38	99.84	99.84	99.84	45	134.33
TWIN BUTTE	W	E	2	1986	10	5.3	99.934	99.88	91.72	33.33	84
TWIN BUTTE	W	F	2	1986	10	5.25	99.914	99.89	67.83	23	62.25
TWIN BUTTE	W	G	2	1986	10	5.5	99.828	99.68	122.64	30.3	66
TWIN BUTTE	W	H	2	1986	10	5.33	99.744	99.84	122.49	34	81.5
TWIN BUTTE	W	I	2	1986	10	5.53	99.8	99.81	105.44	40.2	105.3
TWIN BUTTE	W	J	2	1986	10	5.57	99.91	99.76	112.3	42.6	112.2
TWIN BUTTE	W	K	2	1986	10	5.66	99.782	99.73	100.78	77.14	153.86
TWIN BUTTE	W	L	2	1986	10	5.46	99.777	99.78	100.79	35.25	71.75

Table 2. Outlier analysis statistics

Site	Block	Depth	Year	Indicator	Means	stderr	std	Numb_OBS	Comments
TWIN BUTTE	W	10	1986	BC_Al	102.11	9.62	31.91	11	Removed Outlier
TWIN BUTTE	W	10	1986	Ca_Al	40.60	4.56	15.13	11	Removed Outlier
TWIN BUTTE	W	10	1986	BC_Al	174.35	72.77	252.09	12	
TWIN BUTTE	W	10	1986	Ca_Al	88.96	48.55	168.17	12	
TWIN BUTTE	W	10	2001	BC_Al	165.93	22.80	75.62	11	Removed Outlier
TWIN BUTTE	W	10	2001	Ca_Al	73.88	10.89	36.11	11	Removed Outlier
TWIN BUTTE	W	10	2001	BC_Al	188.90	31.00	107.39	12	
TWIN BUTTE	W	10	2001	Ca_Al	84.28	14.38	49.83	12	

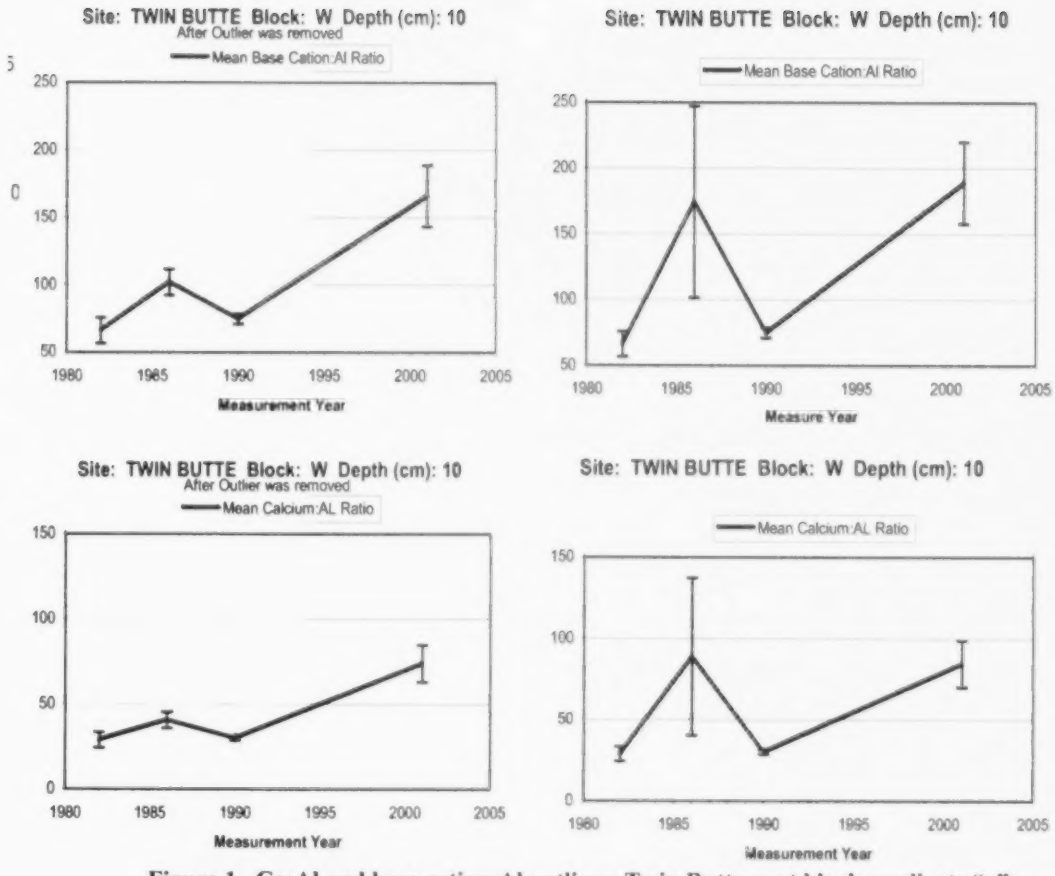


Figure 1. Ca:Al and base cation:Al outliers: Twin Butte west block, replicate "a"

Charts on the left exclude the outliers; charts on the right include the outliers.